

**WHAT IS CLAIMED IS:**

1. A semiconductor device comprising:
  - a gate insulating film formed on a substrate; and
  - 5 a gate electrode formed on the gate insulating film;
  - the gate insulating film comprising:
    - a high dielectric constant film containing a metal, oxygen and silicon; and
    - 10 a lower barrier film formed below the high dielectric constant film and containing the metal, oxygen, silicon and nitrogen.

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2. The semiconductor device according to claim 1, wherein
  - the gate insulating film comprises an upper barrier film formed above the high dielectric constant film, and
  - 15 the upper barrier film contains the metal, oxygen and nitrogen.

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3. The semiconductor device according to claim 1, wherein
$$0.23 \leq y/(x+y) \leq 0.90$$

when a composition of the high dielectric constant film is expressed as  $M_xSi_yO$ , where M, O and Si represent the metal, oxygen and silicon, respectively, and  $x > 0$  and  $y > 0$ .

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4. The semiconductor device according to claim 1, wherein
$$0.23 \leq y/(x+y) \leq 0.30$$

when a composition of the high dielectric constant film is expressed as  $M_xSi_yO$ , where M, O and Si represent the metal, oxygen and silicon, respectively, and  $x > 0$  and  $y > 0$ .

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5. The semiconductor device according to claim 1, wherein
$$x/(x+y) \geq 0.10$$

when the metal is hafnium or zirconium, and  
a composition of the lower barrier film is expressed as  $M_xSi_yON$ , where M, O, Si  
and N represent the metal, oxygen, silicon and nitrogen, respectively, and  $x > 0$  and  $y > 0$ .

5     6. The semiconductor device according to claim 1, wherein the gate electrode is a metal  
gate electrode.

7. A method for producing a semiconductor device comprising the steps of:  
forming a high dielectric constant film containing a metal, oxygen and a  
10    predetermine substance on a substrate;  
performing a heat treatment with respect to the high dielectric constant film to  
diffuse silicon from the side of the substrate into the high dielectric constant film, thereby  
forming a silicon-containing high dielectric constant film; and  
forming a conductive film for serving as a gate electrode on the silicon-containing  
15    high dielectric constant film.

8. The method for producing a semiconductor device according to claim 7, wherein the  
predetermined substance is hydrogen.  
20    9. The method for producing a semiconductor device according to claim 7, wherein the  
metal is hafnium or zirconium.

10. The method for producing a semiconductor device according to claim 7, comprising  
forming an insulating film containing silicon, nitrogen and the predetermined substance on  
25    the substrate before the step of forming the high dielectric constant film; and  
wherein the step of performing a heat treatment with respect to the high dielectric  
constant film comprises diffusing silicon contained in the insulating film into the high

dielectric constant film, and forming a lower barrier film by diffusing the metal contained in the high dielectric constant film into the insulating film.

11. The method for producing a semiconductor device according to claim 7, wherein

5           the step of forming the high dielectric constant film comprises forming the high dielectric constant film by CVD employing a source precursor containing the metal and the predetermined substance.

12. The method for producing a semiconductor device according to claim 7, wherein

10           the step of forming the high dielectric constant film comprises forming the high dielectric constant film by CVD employing a source precursor containing the metal and a source gas containing the predetermined substance.

13. The method for producing a semiconductor device according to claim 7, wherein

15           the step of forming the high dielectric constant film comprises forming the high dielectric constant film by PVD employing a target containing the metal in an atmosphere containing the predetermined substance.

14. The method for producing a semiconductor device according to claim 7, comprising

20           the step of forming an upper barrier by nitriding a surface of the silicon-containing high dielectric constant film between the step of performing a heat treatment with respect to the high dielectric constant film and the step of forming a conductive film.

15. The method for producing a semiconductor device according to claim 7, comprising

25           the step of forming an upper barrier by nitriding a surface of the high dielectric constant film between the step of forming a high dielectric constant film and the step of performing a heat treatment with respect to the high dielectric constant film.

16. The method for producing a semiconductor device according to claim 7, wherein  
a temperature for the heat treatment in the step of performing the heat treatment  
with respect to the high dielectric constant film is 600°C or more and 850°C or less.

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17. The method for producing a semiconductor device according to claim 7, wherein

$$T \leq 6.69 \cdot y/(x+y) + 749.4,$$

when a composition of the silicon-containing high dielectric constant film is  
expressed as  $M_xSi_yO$ , where M, O and Si represent the metal, oxygen and silicon,  
10 respectively, and  $x > 0$  and  $y > 0$ , and a maximum temperature in a production process is  
expressed as T [°C].

18. The method for producing a semiconductor device according to claim 17, wherein

the gate electrode is made of a material containing silicon, and

$$y/(x+y) \leq 0.30.$$

19. The method for producing a semiconductor device according to claim 7, wherein

the gate electrode is a metal gate electrode,

20 the method comprising the step of performing a heat treatment with respect to the  
substrate after the step of forming a conductive film.

20. A method for producing a semiconductor device comprising the steps of:

forming a high dielectric constant film containing a metal, oxygen and hydrogen on  
a substrate;

25 performing a heat treatment with respect to the high dielectric constant film to  
diffuse silicon from the side of the substrate into the high dielectric constant film, thereby  
forming a silicon-containing high dielectric constant film; and

forming a conductive film for serving as a gate electrode on the silicon-containing high dielectric constant film.

21. The method for producing a semiconductor device according to claim 20, wherein the  
5 metal is hafnium or zirconium.

22. The method for producing a semiconductor device according to claim 20, comprising forming an insulating film containing silicon, nitrogen and hydrogen on the substrate before the step of forming the high dielectric constant film; and

10 wherein the step of performing a heat treatment with respect to the high dielectric constant film comprises diffusing silicon contained in the insulating film into the high dielectric constant film, and forming a lower barrier film by diffusing the metal contained in the high dielectric constant film into the insulating film.

15 23. The method for producing a semiconductor device according to claim 20, wherein the step of forming the high dielectric constant film comprises forming the high dielectric constant film by CVD employing a source precursor containing the metal and hydrogen.

20 24. The method for producing a semiconductor device according to claim 20, wherein the step of forming the high dielectric constant film comprises forming the high dielectric constant film by CVD employing a source precursor containing the metal and a source gas containing hydrogen.

25 25. The method for producing a semiconductor device according to claim 20, wherein the step of forming the high dielectric constant film comprises forming the high dielectric constant film by PVD employing a target containing the metal in an atmosphere

containing hydrogen.

26. The method for producing a semiconductor device according to claim 20, comprising the step of forming an upper barrier by nitriding a surface of the silicon-containing high dielectric constant film between the step of performing a heat treatment with respect to the high dielectric constant film and the step of forming a conductive film.  
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27. The method for producing a semiconductor device according to claim 20, comprising the step of forming an upper barrier by nitriding a surface of the high dielectric constant film between the step of forming a high dielectric constant film and the step of performing a heat treatment with respect to the high dielectric constant film.  
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28. The method for producing a semiconductor device according to claim 20, wherein a temperature for the heat treatment in the step of performing the heat treatment with respect to the high dielectric constant film is 600°C or more and 850°C or less.  
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29. The method for producing a semiconductor device according to claim 20, wherein  $T \leq 6.69 \cdot y/(x+y) + 749.4$ , when a composition of the silicon-containing high dielectric constant film is expressed as  $M_xSi_yO$ , where M, O and Si represent the metal, oxygen and silicon, respectively, and  $x > 0$  and  $y > 0$ , and a maximum temperature in a production process is expressed as T [°C].  
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30. The method for producing a semiconductor device according to claim 29, wherein the gate electrode is made of a material containing silicon, and  
25  $y/(x+y) \leq 0.30$ .

31. The method for producing a semiconductor device according to claim 20, wherein  
the gate electrode is a metal gate electrode, and  
the method comprising the step of performing a heat treatment with respect to the  
substrate after the step of forming a conductive film.

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